

# Model-Based Enterprise Framework for Aerospace Manufacturing Engineering

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**Abstract.** In the context of aerospace digital transformation, gaining and maintaining competitive advantage has led aerospace manufacturers to change how product definition is communicated. Model-Based Definition (MBD) and Enterprise (MBE) are the next generations of product definition that aim to move from 2D drawings to a full 3D digital model. Even though traditional engineering drawings still play an essential role in product development, developing an MBE today, for an aerospace company, deals primarily with its fundamentals: how significant benefits are? This work focuses on defining the MBE value stream framework and evaluating the potential improvements that can be realised for MBE within an aerospace manufacturing engineering (ME) context. To achieve this aim, a methodological triangulation has been adopted through the framework. Based on a ME business case and value stream case study, findings suggest a significant reduction of manufacturing lead-time and cost as well as an improved quality of both the product and the process, resulting in less rework. The developed framework and analysis method have been successfully applied and validated to two different aerospace ME processes. Based on a data-driven approach, it proposes a reliable evaluation of potential improvements for MBE. Successful implementation of the MBE concept relies on maximising its potential benefits. Hence, this industrial research project and its key findings contribute to the development of a strategy for implementing MBE within the aerospace manufacturing company to enable a lean and efficient consumption of product definition.

**Keywords.** Model-Based Definition, Metrics-Based Process Mapping, Methodological Triangulation, Potential Improvements.

## 1. Introduction

Within an industrial context, over the last century, the manufacturing industry has been built upon a firm foundation of human-readable 2D technical drawings [1]. Engineers typically create product definitions using a combination of 3D models and 2D drawings. The 3D model defines the nominal shape of the product only and is used throughout the value stream to undertake activities such as analysis and simulations whereas 2D drawings are the prime artefact to define the characteristics of a conforming product.

With the latest digital development, it is possible to insert associative 3D data for product definition, development, manufacturing and inspection into the CAD model,

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eliminating the need for drawings. This is known as Model-Based Definition (MBD) which aims to be consumed within the downstream processes across all functions in business, creating a complete digital flow of information called Model-Based Enterprise (MBE).

The National Institute of Standards & Technology (NIST) defines MBD as an annotated CAD model that contains all the information needed to define a product. This annotated model replaces the traditional drawings. To deepen this definition, MBD is using 3D models with Product Manufacturing Information and associated meta- data within 3D CAD software to define or provide specifications for individual components and product assemblies. The goal of MBD is to create 3D Technical Data Packages (TDP) to be used for manufacture, logistics, and acquisition [2]. A 3D master can be seamlessly shared with people across the value chain and MBD consists in the digital thread that all functions in the business consume [3]. The core MBE principle relies on creating data once and reusing it directly among all data consumers [4].

The automotive and aerospace sectors are leading the development to adopt a full MBE. With no need of technical drawings, the design, manufacturing and inspection processes are accelerated [5]. At this point, industries understand the theoretical benefits: MBE takes less time to create products and reduces downstream errors and delays due to their unambiguous nature. However, that kind of advantage has not been deeply developed in some measured improvements [6].

Value Stream Mapping (VSM) and Metrics-Based Process Mapping (MBPM) are lean management tools enabling to capture the potential improvements within a factory. While VSM depicts and improves mainly the physical flow in a company, MBPM is more focused on the information flow. To make effective process measurement and analysis, understanding the current-state performances requires the use of key process metrics to enable data-driven decisions and improvements [7]. This has led to this effort to apply value stream techniques in the development of MBE.

Even though many studies discuss the MBE attributes and adoption, a lack of research in improvements and quantified benefits being found. When the VSM method is largely applied, absence of MBPM case studies has been identified. The challenge is to develop a method which uses MBPM and shows the relevant metrics data and analysis while being user-friendly, illustrative and close to the business reality. No approach to developing the value stream of MBE has been determined and applied to a specific organisation. This research aims at proposing an enhanced MBE value stream framework. The proposed approach focuses on capturing the opportunity for MBE within a business and extracting the quantified benefits from the value stream applied to different ME processes.

## **2. Methodology**

The methodology includes six steps with three major phases which includes project initiation, development, and completion.

During Phase-1, meetings with key stakeholders were done to capture the requirements along with analysis of academic research and available industrial case studies. In Phase-2 internal workshops and suppliers survey were done to understand the capability and a mathematical model was built to quantify MBE benefits. Then, prioritisation of value areas was made by numerical distribution of effort per activity and trade-off with the scoring approach in order to obtain a prioritisation matrix of the

industrial case study. In the next step value stream was developed by mapping the process, identification of type and causes of waste, area of improvements and future requirements to enhance process flow. This followed the comparison of multiple results through deep data analysis from business performance, assessment through comparison with literature and evaluation of improvements through methodological triangulation as shown in Figure 1. In the final phase the findings, approaches, business feasibility, technical data and proposed future improvements were all validated through expert opinion and case study.

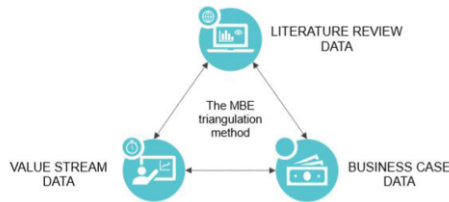


Figure 1. Methodological Triangulation to evaluate MBE Improvements

3. Development of MBE Framework

3.1. As-Is Industrial Practice and Knowledge

A literature benchmark for quantified MBD/E improvements among the industry has been conducted based on seven surveys or data points in the literature review. Figure 2(a) is representative of 600 respondents of which 35% are from the aerospace industry. It has shown that rework, scrap, and production time constitute the major improvement noticed when adopting MBD/E.

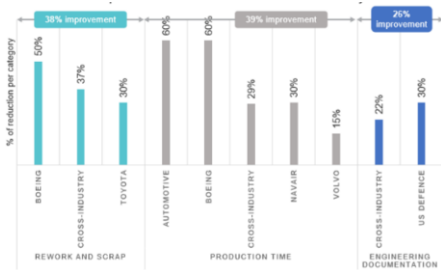


Figure 2(a). Improvements noticed with MBD/E in industry

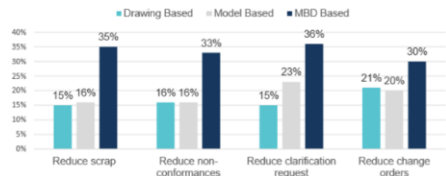


Figure 2(b). Rework reduction noticed according to the level of adoption

Among the average 38% saved in rework and scrap, it includes the reduction of nonconformance, clarification request, and change orders as shown in Figure 2(b) [6]. In the context of the manufacturing company, currently, product definition is consumed and documented through the paper thread. For example, the design of a component requires more than one thousand separate items to be created, leading to complex downstream documentation. The ME represents 400 pages of documentation without formal linkage; creating and managing this information manually becomes very time-consuming. The transition to MBD would allow building directly each of the 1,000

pages in the master model, thus creating a “digital thread” across all departments and services.

3.1.1. The Model-based Enterprise Phases

As MBE requires heavy IT systems integration to automatically consume product definition, therefore, a progressive application is considered. This will enable the manufacturing company to mature their approach to creating MBDs, develop and gain regulatory approvals and to build familiarity in the organisation and following it, automation of elements of the manufacturing and maintenance value stream to enable an MBE.

3.2. The Model-Based Enterprise Framework

To define the MBE Value Stream, a four-stage framework has been created as shown in Figure 3 aiming to evaluate the MBD improvements within the company for ME activities. Based on the triangulation methodology which consists in evaluating and measuring the same phenomenon using three different methods [8], the framework will be the key to compare two more results in addition to the literature benchmark: the business case and the value stream.

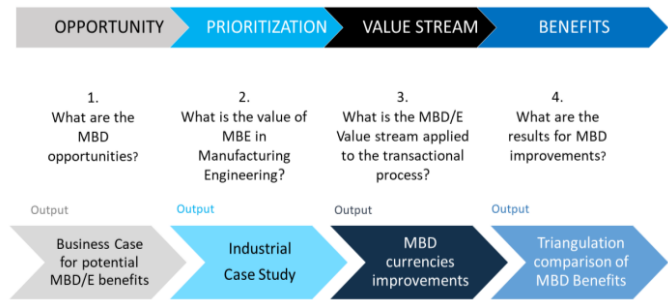


Figure 3. MBE Framework Global structure

3.2.1. Opportunity

Starting with capturing the potential benefits with MBD within all ME activities in the business, several workshops have been held to identify the likely magnitude of the potential benefits to creating a business case. All data has been normalised to obtain a coherent analysis. From the workshops, foreseen benefits have been captured in terms of process time, lead time and some qualitative.

With the effort breakdown of the ME tasks, the final MBD opportunities have been captured in terms of process time and cost savings. On a global perspective, the business case demonstrates an improvement of 47% in time when adopting MBD in ME.

3.2.2. Prioritisation. Where is the value for MBE in Manufacturing Engineering?

In addition to the forecasted improvements, the current workload per task has been analysed by a numerical distribution of effort in ME. Hence, combining the MBE initial benefits for each activity and its effort required, a trade-off approach has been followed to prioritise the tasks and obtain the industrial case study.

To find an optimal trade-off between the potential improvements and the current workload per task, a scoring method has been set up. This scoring approach consists in assigning a score between 0 and 3 to a task for both the effort and the improvements to obtain an overall score per activity. Based on experts' views, it is assumed that the MBD improvement counts twice compared to the effort. Thus, a prioritisation matrix has been created with an overall score going from 0 to 9. Based on the prioritisation matrix, the industrial case study has been selected by choosing the category where both the improvement and current workload were high.

### *3.2.3. Value Stream*

Aiming to create the value stream for MBE in ME, a Metrics-Based Process Mapping approach has been followed. MBPM provides the same outputs as VSM but is carried out at a process level. For this reason, it has been applied to the selected transaction process. This enabled to obtain the MBD improvements from the business of the sponsoring company. The results show that rework is the main benefit (79%) from MBD implementation in the business due to standardised and computerised work preventing from manual errors. Following that, Process time showed 37% and Lead Time showed 23% improvement.

### *3.2.4. Benefits: The Results for MBD Improvements*

In this final step of the framework, the MBD improvements were compared and evaluated from the three sources of data. Deep data analysis of the business performances has enabled to compare the results from the value stream as well as from the business case and the literature benchmark. The overall MBD benefits have been evaluated using a methodological triangulation which consists in measuring the same phenomenon using three different methods.

The value stream activity, as well as the literature data, confirm the business case hypotheses to give confidence in the results. Triangulation of MBE improvements provides reliability and credibility in the foreseen benefits, which is essential to the sponsoring company to establish a solid strategy.

## **4. Validation**

The suitability and efficiency of the proposed framework were demonstrated through the achievement of a successful application and possible integration within the business practices. The ongoing validation was followed all along the process with key stakeholders and experts to ensure that the metrics were well defined and data collected was realistic. In business case validation, the first one was not validated forcing to develop a second business case on proven assumptions from the organisation, which was validated from the stakeholders with some modifications. Additionally, the scoring criteria and methodology were verified by key stakeholders who validated the resulting prioritisation matrix. Therefore, considering the demonstrated importance of the transactional process and the data availability within the sponsoring company, the case study was approved. An extra case study on Manufacturing Acceptance Standard (MAS) was also done to validate the method. The results from this second case study reinforced the approach and benefits.

## 5. Conclusion and Future Work

The developed framework and analysis method was successfully applied and validated to two different aerospace ME processes. The proposed approach allowed to evaluate and quantify the potential improvements for MBE. The data-driven approach adopted through value stream can be used for decision making on MBE implementation within the business. While the framework proposed reliable improvements, it has been proven that MBD would contribute to a large reduction in rework and time in ME. Finally, it will contribute to the development of a strategy for implementing MBE in the manufacturing company to enable a lean and efficient consumption of product definition.

Some future work opportunities have been identified in order to enhance MBE capabilities and improve the developed framework. The application of the framework to all ME activities would require further work to fully certify the business case. As all departments (design, manufacturing, etc.) are likely to be impacted differently by MBE, an extended vision of the improvements could be investigated. In order to consider supply chain readiness, the scope of the framework can be extended to external processes. The developed business case should be expanded to include the costs of implementation, for a holistic Return on Investment. Heading towards the implementation, as a supplement to MBD adoption, some lean initiatives, such as process rearrangement, should be developed to fully capture the improvements with MBE. The project provides valuable results for MBD potential improvements, yet further work would give ‘before-and-after’ results from a long-term perspective. This would yield interesting data for other organisations who intend to move towards a Model-Based Enterprise.

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